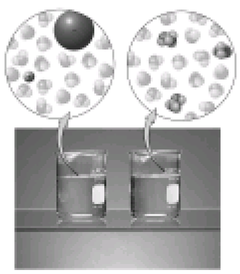
Chapter 4

Chemical Reactions: An Introduction

Concept Check 4.1



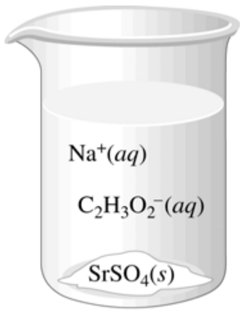
LiI(*s*) and $CH_3OH(l)$ are each introduced into a separate beaker containing water. Using the drawings shown here, label each beaker with the appropriate compound and indicate whether you would expect each substance to be a strong electrolyte, weak electrolyte, or nonelectrolyte. (In order to arrive at the correct answer(s), viewing the color text version of the figure associated with this problem is advisable.)

Solution

The left beaker contains two types of individual atoms (ions) and no solid, therefore it must represent the soluble, LiI. Because Li is a soluble ionic compound, it is an electrolyte. The beaker on the right represents a molecular compound that is soluble but not dissociated in solution. Therefore, it must be the CH_3OH. Because the CH_3OH is not dissociated in solution and no ions are present, it is a nonelectrolyte.

Concept Check 4.2

Your lab partner tells you that she mixed two solutions that contain ions. You analyze the solution and find that it contains the ions and precipitate shown in the beaker.



a. Write the molecular equation for the reaction.
b. Write the complete ionic equation for the reaction.
c. Write the net ionic equation for the reaction.

Solution

a. In order to solve this part of the problem, keep in mind that this is an exchange (metathesis) reaction. Since you are given the products in the picture, you need to work backward to determine the reactants. Starting with the solid $SrSO_4(s)$, you know that the SO_4^{2-} anion started the reaction with a different cation (not Sr^{2+}). Since Na^+ is the only option, you can conclude that one of the reactants must be Na_2SO_4. Based on solubility rules, you know that the Na_2SO_4 is soluble, so you represent it as $Na_2SO_4(aq)$. The remaining cation and anion indicate that the other reactant is the soluble $Sr(C_2H_3O_2)_2$. Observing the soluble and insoluble species in the picture, you conclude that the molecular equation is

$$Na_2SO_4(aq) + Sr(C_2H_3O_2)_2(aq) \rightarrow SrSO_4(s) + 2NaC_2H_3O_2(aq)$$

b. Writing the strong electrolytes in the form of ions and the solid with its molecular formula, the complete ionic equation for the reaction is

$$2Na^+(aq) + SO_4^{2-}(aq) + Sr^{2+}(aq) + 2C_2H_3O_2^-(aq) \rightarrow SrSO_4(s) + 2Na^+(aq) + 2C_2H_3O_2(aq)$$

c. After canceling the spectator ions, the net ionic equation for the reaction is

$$Sr^{2+}(aq) + SO_4^{2-}(aq) \rightarrow SrSO_4(s)$$

Concept Check 4.3

At times, we want to generalize the formulas of certain important chemical substances: acids and bases fall into this category. Given the following reactions, try to identify the acids, bases, and some examples of what the general symbols (M and A^-) represent.

a. $MOH(s) \rightarrow M^+(aq) + OH^-(aq)$
b. $HA(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + A^-(aq)$
c. $H_2A(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + HA^-(aq)$

d. For parts a. to c., give real examples for M and A.

e. Solution

a. MOH must be a base since OH^- is being produced in solution. It is a strong base because the reaction indicates that MOH is completely soluble (strong electrolyte). In order to maintain charge balance in the formula, the element M must be a 1+ cation, probably a metal from Group IA of the periodic table. Examples of bases that fall into this category include NaOH and KOH.

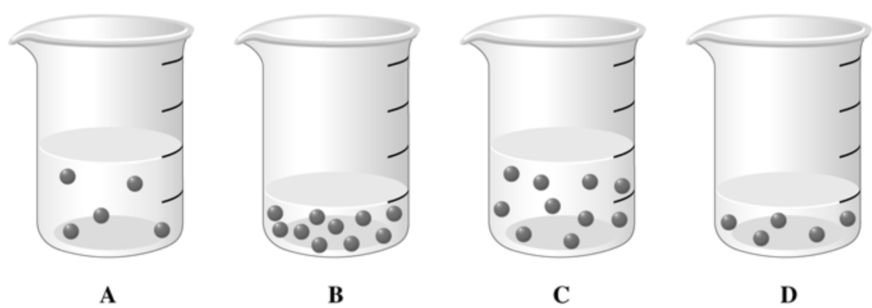
b. This must be an acid since H^+ is being produced in solution. It is a weak acid because the double arrow is used, indicating only partial ionization in solution. From the chemical reaction, A^- represents an anion with a 1- charge. Acetic acid, $HC_2H_3O_2$, is a weak acid of this type.

c. This must be an acid since H^+ is being produced in solution. H_2A(*aq*) is a weak acid because the equation indicates only partial ionization in solution. A represents an anion with a 2- charge. Carbonic acid, H_2CO_3, is a weak acid of this type.

d. Examples of M include Na^+, K^+, and Li^+. Examples of A for reaction b. include F^-, $C_2H_3O_2^-$, and CN^-. Examples of A for reaction c. include S^{2-}, CO_3^{2-}, and $C_4O_4O_6^{2-}$.

Concept Check 4.4

Consider the following beakers. Each contains a solution of the hypothetical atom X.



a. Arrange the beakers in order of increasing concentration of X.

b. Without adding or removing X, what specific things could you do to make the concentrations of X equal in each beaker? (*Hint:* Think about dilutions.)

Solution

a. In order to answer this question, you need to compare the number of atoms of X per unit of volume. In order to compare volumes, use the lines on the sides of the beakers. Beaker A has a concentration of 5 atoms per 2 volume units, 5/2 or 2.5/1. Beaker B has a concentration of 10 atoms per 1 volume unit, 10/1. Beaker C has a concentration of 10 atoms per 2 volume units, 10/2 or 5/1. Beaker D has a concentration of five atoms per volume unit, 5/1. Comparing the concentrations, the ranking from highest to lowest concentration is: Beaker B > Beaker C = Beaker D > Beaker A.

b. To make the concentrations of X equal in each beaker, they all have to be made to match the beaker with the lowest concentration. This is Beaker A, which has 5 atoms of X in one-half a beaker of solution. To make the concentrations equal, do the following: double the volume of Beakers C and D, and quadruple the volume of Beaker B. Overall, Beakers A and B will contain a full beaker of solution, and Beakers C and D will contain a half-beaker of solution.

Concept Check 4.5

Consider three flasks, each containing 0.10 mol of acid. You need to learn something about the acids in each of the flasks, so you perform titration using an NaOH solution. Here are the results of the experiment:

Flask A	10 mL of NaOH required for neutralization
Flask B	20 mL of NaOH required for neutralization
Flask C	30 mL of NaOH required for neutralization

a. What have you learned about each of these acids from performing the experiment?

b. Could you use the results of this experiment to determine the concentration of the NaOH? If not, what assumption about the molecular formulas of the acids would allow you to make the concentration determination?

Solution

a. Since flask C required three times the amount of titrant (NaOH) as acid A, you have learned that acid C has three times as many acidic protons as acid A. Since flask B required two times the amount of titrant as acid A, you have also learned that acid B has two times as many acidic protons as acid A.

b. If you assume that acid A contains a monoprotic acid, then you know the number of moles of A in the flask. After performing the titration, you know that the moles of NaOH must equal the moles of acid in flask A. You take the number of moles of NaOH and divide it by the volume of NaOH added during the titration to determine the concentration of the NaOH solution.

Conceptual Problem 4.15

You need to perform gravimetric analysis of a water sample in order to determine the amount of Ag^+ present.

a. List three aqueous solutions that would be suitable for mixing with the sample to perform the analysis.
b. Would adding KNO_3(*aq*) allow you to perform the analysis?
c. Assume you have performed the analysis and the silver solid that formed is moderately soluble. How might this affect your results?

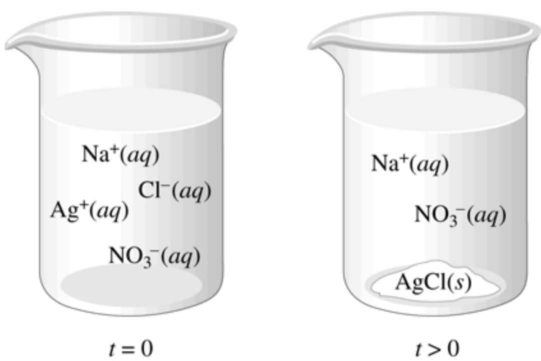
Solution

a. Any soluble salt that will form a precipitate when reacted with Ag^+ ions in solution will work, for example: $CaCl_2$, Na_2S, $(NH_4)_2CO_3$.
b. No, no precipitate would form.
c. You would underestimate the amount of silver present in the solution.

Conceptual Problem 4.16

In this problem you need to draw two pictures of solutions in beakers at different points in time. Time zero ($t = 0$) will be the hypothetical instant at which the reactants dissolve in the solution (*if* they dissolve) *before* they react. Time after mixing ($t > 0$) will be the time required to allow sufficient interaction of the materials. For now, we assume that insoluble solids have no ions in solution and do not worry about representing the stoichiometric amounts of the dissolved ions. Here is an example.

Solid NaCl and solid $AgNO_3$ are added to a beaker containing 250 mL of water. Note that we are not showing the H_2O and we are representing only the ions and solids in solution.



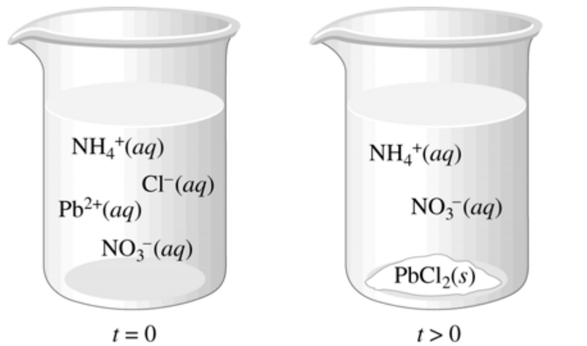
Using the same conditions as the example (adding the solids to H_2O), draw pictures of the following:

a. solid lead(II) nitrate and solid ammonium chloride at $t = 0$ and $t > 0$
b. FeS(*s*) and $NaNO_3$(*s*) at $t = 0$ and $t > 0$

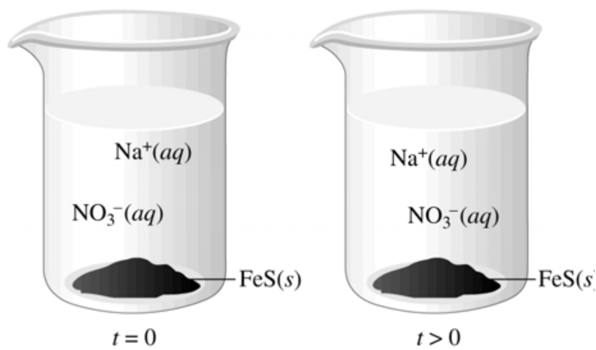
c. solid lithium iodide and solid sodium carbonate at $t = 0$ and $t > 0$

Solution

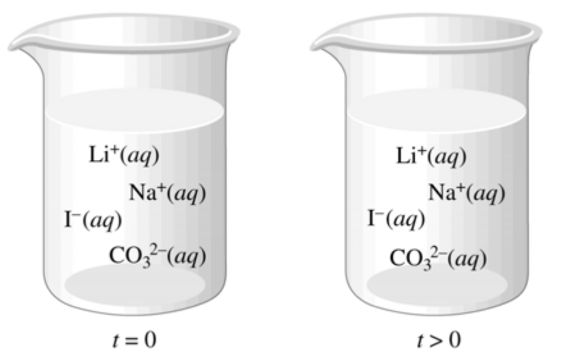
a.



b.



c.



Conceptual Problem 4.17

You come across a beaker that contains water, aqueous ammonium acetate, and a precipitate of calcium phosphate.

a. Write the balanced molecular equation for a reaction between two solutions containing ions that could produce this solution.
b. Write the complete ionic equation for the reaction in part a.
c. Write the net ionic equation for the reaction in part a.

Solution

a. $3Ca(C_2H_3O_2)_2(aq) + 2(NH_4)_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NH_4C_2H_3O_2(aq)$
b. $3Ca^{2+}(aq) + 6C_2H_3O_2^{-}(aq) + 6NH_4^{+}(aq) + 2PO_4^{3-}(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NH_4^{+}(aq) + 6C_2H_3O_2^{-}(aq)$
c. $3Ca^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Ca_3(PO_4)_2(s)$

Conceptual Problem 4.18

Three acid samples are prepared for titration by 0.01 *M* NaOH:
Sample 1 is prepared by dissolving 0.01 mol of HCl in 50 mL of water.
Sample 2 is prepared by dissolving 0.01 mol of HCl in 60 mL of water.
Sample 3 is prepared by dissolving 0.01 mol of HCl in 70 mL of water.

a. Without performing a formal calculation, compare the concentrations of the three acid samples (rank them from highest to lowest).
b. When performing the titration, which sample, if any, will require the largest volume of the 0.01 *M* NaOH for neutralization?

Solution

a. Sample 1, Sample 2, Sample 3
b. They all will require the same volume of 0.1 *M* NaOH.

Conceptual Problem 4.19

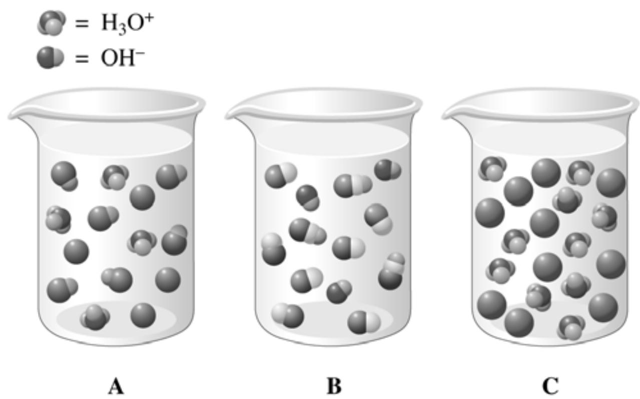
Would you expect a precipitation reaction between an ionic compound that is an electrolyte and an ionic compound that is a nonelectrolyte? Justify your answer.

Solution

Probably not, since the ionic compound that is a nonelectrolyte is not soluble.

Conceptual Problem 4.20

Equal quantities of the hypothetical strong acid HX, weak acid HA, and weak base BZ, are each added to a separate beaker of water, producing the solutions depicted in the drawings. In the drawings, the relative amounts of each substance present in the solution (neglecting the water) are shown. Identify the acid or base that was used to produce each of the solutions (HX, HA, or BZ). (In order to arrive at the correct answer(s), viewing the color text version of the figure associated with this problem is advisable.)



Solution

A good starting point is to identify the solution that contains the base. Since bases produce OH^- in aqueous solution, we would expect to see OH^- present in the BZ solution. The center beaker depicts OH^- in the solution so it must be the base. By default, the remaining two beakers must contain acid. This is confirmed by the presence of H_3O^+ in both the left and right beakers. Keeping in mind that weak acids only partially dissociate, for the weak acid HA, we would expect to observe HA, H_3O^+, and A^- in the solution. In the case of the strong acid, HX, that completely dissociates, we would expect to observe only H_3O^+ and X^- in the solution. The beaker on the right only has H_3O^+ and one other species in solution so it must be the strong acid HX. Examining the beaker on the left, there are three species present, which indicates that it must be the weak acid.